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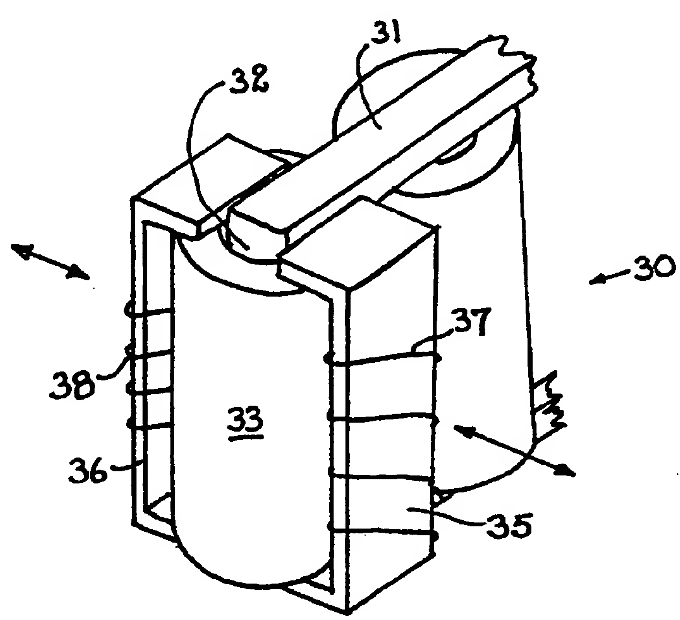
(54) Title: TRANSFORMER WITH REGULATING MEANS

(57) Abstract

A transformer (30) including a core (31), a first winding (34) to be regulated wound around a limb (32) of the core (31), at least one regulation second winding (37, 38) and moving means for moving the regulating winding(s) relative to first winding (34), whereby in use of the transformer (30) there is a leakage flux at opposite ends of the first winding (34). The transformer (30) further includes flux collecting means (35, 36) separate from the core (31) and comprising the at least one second winding (37, 38). The first and second winding(s) are connected in series.



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Transformer with Regulating Means

Technical Field

This invention relates to a transformer with regulating means. In particular, but not exclusively, the invention relates to dry transformers having windings formed from cables having solid electrical insulation. The invention has particular application to power transformers having rated outputs from a few hundred kVA to more than 1000 MVA and rated voltages from 3-4 kV to very high transmission voltages, e.g. from 400-800 kV or higher.

Background of the Invention

Conventionally voltage regulation of a power transformer is achieved using an on-load tap changer. However there are a number of disadvantages in using tap-changers in power transformers. Normally the on-load tap changer is positioned in a transformer tank containing transformer oil for cooling and electrical insulation purposes. However during operation, arcing and sparking occur within the transformer tank leading to degradation of the transformer oil. The failure statistics for oil-cooled and/or oil insulated power transformers show that it is often the on-load tap changers which fail. Another disadvantage in using a tap changer for regulating purposes is that regulation is only provided in a finite number of steps. A further disadvantage of tap changers is the need to have a number of leads associated with each tap.

Summary of the Invention

One aim of the present invention is to provide, in a power transformer, a novel means of regulation which does not involve the use of a tap changer.

Another aim of the present invention is to use the leakage flux in a transformer to regulate the voltage of the transformer.

According to the present invention there is provided a transformer including a core having a core limb, a first winding to be regulated wound around the core limb and having opposite ends, at least one regulating second winding and moving means for moving the at least one second winding relative to the first winding, whereby in use of the transformer there is a leakage flux at opposite ends of the first winding, characterised in that the transformer further includes flux collecting means which is separate from the core, which comprises said at least one second winding and which is arranged to provide a leakage flux path from one to the other end of the first winding and in that said at least one second winding is connected in series with said first winding.

Normally leakage flux in a transformer is undesirable. However the present invention makes use of the leakage flux from the ends of a transformer winding for controlling or regulating the transformer.

Conveniently the flux collecting means comprises at least one core piece, separate from the said core, on which the at least one second winding is wound, the or each core piece having opposite end portions arranged at opposite ends of the first winding and a connecting portion connecting the end portions. Suitably, the at least one second winding is wound on the connecting portion of the at least one core piece. Two such core pieces may be provided which are arranged on opposite sides of the first winding. Alternatively, a core package of at least two core pieces may be arranged on each side of the first winding. In this latter case the two second windings of each core package are conveniently wound in opposite directions on the two cor pieces of the core package. The cor pieces of each core

package are preferably mounted for movement together relative to the first winding.

Instead of the flux collecting means comprising core pieces, the flux collecting means may comprise the said at least two second windings arranged at opposite ends of the first winding, the or each second winding at one end of the first winding being connected to a different second winding at the other end of the first winding.

Preferably said moving means are arranged to move parts of the flux collecting means relative to the first winding to control the voltage regulation.

Preferably the first winding and/or the or each second winding is wound from cable having inner electrically conducting means and surrounding outer solid electrically insulating means preferably comprising magnetically permeable plastics material within which the electric field is confined in use of the transformer. Preferably the electrically insulating means is of substantially unitary construction comprising an inner layer of semiconducting material in electrical contact with said electrically conducting means, an outer layer of semiconducting material at a controlled electrical potential along its length and an intermediate layer of electrically insulating material between the said inner and outer layers.

In this specification the term "semiconducting material" means a material which has a considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an electrical insulator. Typically, but not exclusively, the semiconducting material should have resistivity of from 1 to 10^5 ohm-cm, preferably from 10 to 500 ohm-cm and most preferably from 50 to 100 ohm-cm.

The electrically insulating means is of unitary form with the layers either in close mechanical contact or, more

preferably, joined together, e.g. bonded by extrusion. The layers are preferably formed of plastics material having resilient or elastic properties at least at ambient operating temperatures. This allows the cable forming the winding to be flexed and shaped into the desired form of the winding. By using for the layers only materials which can be manufactured with few, if any, defects having similar thermal properties, thermal and electric loads within the insulation are reduced. In particular the insulating intermediate layer and the semiconducting inner and outer layers should have at least substantially the same coefficients of thermal expansion (α) so that defects caused by different thermal expansions when the layers are subjected to heating or cooling will not arise. Ideally the layers will be extruded together around the conducting means.

Conveniently the electrically insulating intermediate layer comprises solid thermoplastics material, such as low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), cross-linked materials, such as cross-linked polyethylene (XLPE), or rubber insulation, such as ethylene propylene rubber (EPR), ethylene-propylene-diene monomer (EPDM) or silicone rubber. The semiconducting inner and outer layers may comprise similar material to the intermediate layer but with conducting particles, such as particles of carbon black or metallic particles, embedded therein. Generally it has been found that a particular insulating material, such as EPR, has similar mechanical properties when containing no, or some, carbon particles.

The screens of semiconducting inner and outer layers form substantially equipotential surfaces on the inside and outside of the insulating intermediate layer so that the electric field is confined between the inner and outer layers in the intermediate layer. In the case of concentric semiconducting and insulating layers, the electric field is substantially radial and c nfined within the intermediate layer. In particular, the semiconducting inner layer is

arranged to be in el ctrical contact with, and to be at the same potential as, the conducting means which it surrounds. The semiconducting outer layer is designed to act as a screen to prevent losses caused by induced voltages. Induced voltages in the outer layer could be reduced by increasing the resistance of the outer layer. The resistance can be increased by reducing the thickness of the outer layer but the thickness cannot be reduced below a certain minimum thickness. The resistance can also be increased by selecting a material for the layer having a higher resistivity. On the other hand, if the resistivity of the semiconducting outer layer is too great, the voltage potential midway between adjacent spaced apart points at a controlled, e.g. earth, potential will become sufficiently high as to risk the occurrence of corona discharge in the insulation with consequent erosion of the insulating and semiconducting layers. The semiconducting outer layer is therefore a compromise between a conductor having low resistance and high induced voltage losses but which is easily connected to a controlled potential, typically earth or ground potential, and an insulator which has high resistance with low induced voltage losses but which needs to be connected to the controlled potential along its length. Thus the resistivity ρ_s of the semiconducting outer layer should be within the range $\rho_{min}<\rho_s<\rho_{max}$, where ρ_{min} is determined by permissible power loss caused by eddy current losses and resistive losses caused by voltages induced by magnetic flux and ρ_{max} is determined by the requirement for no corona or glow discharge.

By connecting the semiconducting outer layer to earth potential, or to some other controlled potential, at spaced apart intervals along its length, the need for an outer metal shield and protective sheath to surround the semiconducting outer layer is eliminated. The diameter of the cable is thus reduced allowing more turns to be provided for a given size of core winding.

Conveniently the thickness of the electrically insulating means is reduced along the length of each non-regulating winding from its high voltage end to its low voltage end. In practice the thickness of the electrically insulating means may be reduced in one or more steps.

The transformer is suitably provided with cooling means, e.g. air cooling means or liquid cooling means arranged around the core and windings.

The core conveniently comprises three core limbs arranged in the same plane or in a triangular arrangement, i.e. along the edges of a triangular prism, with a winding assembly including at least one second winding associated with each core limb.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with particular reference to the accompanying drawings, in which:

Figure 1 is a schematic perspective view of an unregulated power transformer;

Figure 2 is a sectional view through a winding turn of the power transformer of Figure 1;

Figure 3 is a schematic perspective view illustrating one embodiment of power transformer according to the invention having voltage regulation of one of its windings;

Figures 4a and 4b are side and top views, respectively, of part of the transformer of Figure 3;

Figure 5 is a circuit diagram illustrating how a winding of th transformer shown in Figure 3 is connected to two regulating windings;

Figure 6 is a schematic perspective view illustrating another embodiment of power transformer according to the invention having voltage regulation of one of its windings;

Figures 7a, 7b and 7c are, respectively, a side view and top views of regulating windings in two different positions of part of the transformer of Figure 6;

Figure 8 is a circuit diagram illustrating how a winding of the transformer shown in Figure 6 is connected to four regulating windings;

Figure 9 is a schematic perspective view illustrating a yet further embodiment of power transformer according to the invention having voltage regulation of one of its windings;

Figures 10a and 10b are side and top views, respectively, of part of the transformer of Figure 9; and

Figure 11 is a circuit diagram illustrating how a winding of the transformer shown in Figure 9 is connected to four regulating windings.

Figure 1 shows an unregulated three-phase laminated core dry power transformer 1. In order to clarify the construction of the transformer 1, certain details, such as connections for the windings, have been omitted from Figure 1. The core of the transformer 1 is of conventional design and comprises three core legs limb 2, 3 and 4 arranged in a common plane and connected by upper and lower yokes 5 and 6. Concentrically arranged winding turns 7, 8 and 9 are positioned around each of the core limbs. Typically the innermost winding turn 7 represents a primary winding and the two outer winding turns 8 and 9 represent a secondary winding. Spac d apart strips 10 are positioned outside, so as to lie along the length of, each winding turn. Th se

strips 10 may c mprise electrically conducting strips for holding the winding turns at a controlled potential, e.g. earth potential. Alternatively at least some of the strips 10 may serve as spacing members for the assembly of windings, e.g. to facilitate air cooling of the windings.

Each winding of the transformer is made from winding cable 40 (see Figure 2) having inner conductor means 41 comprising a plurality of conductors and surrounding outer electrical insulation 42.

The electrical insulation 42 is of unified form and comprises an inner layer 43 of semiconducting material, an outer layer 44 of semiconducting material and, sandwiched between these semiconducting layers, an insulating layer 45. At least one of the conductors of the conductor means 41 has its insulation, e.g. varnish insulation, removed therefrom so that the inner layer 43 is in electrical contact with the conductor means 41. The layers 43 - 45 preferably comprise thermoplastics materials in close mechanical contact with, preferably solidly connected to, each other at their interfaces. Conveniently these thermoplastics materials have similar coefficients of thermal expansion and are resilient or elastic at least at ambient operating temperature. Preferably the layers 43 - 45 are extruded together, e.g. through a multi-layer extrusion die, around the inner conducting means to provide a monolithic structure so as to minimise the risk of cavities and pores within the electrical insulation. The presence of such pores and cavities in the insulation is undesirable since it gives rise to corona discharge in the electrical insulation at high electric field strengths.

By way of example only, the solid insulating layer 45 may comprise cross-linked polyethylene (XLPE). Alternatively, however, the solid insulating layer may c mprise other cross-linked materials, low density polyethylene (LDPE), high d nsity polyethylene (HDPE), polypropylene (PP), or rubber insulation, such as ethylene

propylene rubb r (EPR), ethylene-propylene-diene monomer (EPDM) or silicone rubber. The inner and outer layers 43 and 44 of semiconducting material may comprise, for example, a base polymer of the same material as the solid insulating layer 45 and highly electrically conductive particles, e.g. particles of carbon black or metal, embedded in the base polymer. The resistivity of these semiconductive layers may be adjusted as required by varying the type and proportion of carbon black added to the base polymer. The following gives an example of the way in which resistivity can be varied using different types and quantities of carbon black.

Base Polymer	Carbon Black Type	Carbon Black Quantity (%)	Volume Resistivity Ω-cm
Ethylene vinyl acetate copolymer/ nitrite rubber	EC carbon black	~15	350-400
-"-	P-carbon black	~37	70-10
-"-	Extra conducting carbon black, type I	~35	40-50
-"-	Extra conducting black, type II	~33	30-60
Butyl grafted polyethylene	-"-	~25	7-10
Ethylene butyl acrylate copolymer	Acetylene carbon black	~35	40-50
-"-	P carbon black	~38	5-10
Ethylene propene rubber	Extra conducting carbon black	~35	200-400

The outer semiconducting layer 44 is connected at spaced apart regions along its length to a controlled potential, e.g. via the strips 10 in the form of electrical conductors. In most practical applications this controlled potential will be earth or ground potential, the specific spacing apart of adjacent earthing points, i.e. the spacing apart of the earthing strips 10, being dependent on the resistivity of the layer 44.

Although not shown the transformers may be provided with conventional air or liquid cooling means.

The semiconducting layer 44 acts as a static shield and as an earthed outer layer which ensures that the electric field of the winding cable is retained within the solid insulation between the semiconducting layers 43 and 44. Losses caused by induced voltages in the layer 44 are reduced by increasing the resistance of the layer 44. However, since the layer 44 must be at least of a certain minimum thickness, e.g. no less than 0.8 mm, the resistance can only be increased by selecting the material of the layer to have a relatively high resistivity. The resistivity cannot be increased too much, however, else the voltage of the layer 44 mid-way between two adjacent earthing points will be too high with the associated risk of corona discharges occurring.

The thickness of the electrical insulation need not be uniform along the length of the winding. The thickness needs to be greater for high voltages and need not be as thick for lower voltages. Accordingly the thickness of the electrical insulation may be stepped along its length, the thicker insulation being at the high voltage end(s) of the winding. Cables with different insulation thicknesses may be joined together to form a particular winding.

The power transformer 1 may be modified by the addition of regulating windings, as shown in each of the embodiments of Figures 3, 6 and 9, to provide a transformer according to the invention with regulation. In the power transformers shown in Figures 3, 6 and 9, the cores and primary and secondary windings wound thereon are substantially similar to those of the transformer 1 and will not be further described in detail. In the following description of the transformers shown in Figures 3, 6 and 9, regulation of only one of the winding assemblies around one of the core limbs of each transformer will be described although, in practic , regulation of the winding assemblies

around each cor limb would b provided. Where possible the same reference numerals have been used to represent the same or similar parts of the different power transformers.

Figures 3, 4a and 4b show a power transformer 30 including a core 31 having a core limb 32. A winding assembly 33 is wound on the core limb 32 and includes a main winding 34 (see Figure 5) to be regulated. A pair of core pieces 35, 36, separate from the core 31, are movably mounted on opposite sides of a core plane containing the three core limbs of the core. Each core piece 35 (36) comprises spaced apart end portions 35a, 35b (36a, 36b) at opposite ends of the winding assembly 33 and a connecting portion 35c (36c) on which a regulating winding 37 (38) is wound. The windings 34, 37 and 38 are connected in series as shown in Figure 5. The windings 37 and 38 are preferably formed from similar winding cable as the winding cable 40 - i.e. having inner electrical conductor means and surrounding solid outer electrical insulation comprising inner and outer layers of semiconducting material and an intermediate layer of plastics material.

Each core piece 35 (36) serves to "pick up" or collect leakage flux from one end of the winding assembly 33 and to guide the flux to, or to provide a flux path back to, the other end of the winding. In particular the end portions 35a, 35b (36a, 36b) are positioned at opposite ends of the winding assembly 33 in the path of the leakage flux. The amount of leakage flux gathered by the core pieces can be altered by adjusting the spacing apart of each core piece from the core limb 32, the movement of the core pieces 35, 36 being indicated by the double headed arrows in Figures 3, 4a and 4b. This adjustment of the positions of the core pieces relative to the core limb 32 or the winding assembly 33 alters the voltage across the regulating windings 37 and 38 provides a regulating function.

Figures 6, 7a and 7b show another embodiment of power transformer 50. The transformer 50 differs from the

transformer 30 in that it has four, instead of two, movably mounted and adjustable core pieces 51 - 54 carrying regulating windings 55 - 58, respectively. The core pieces 51 - 54 are similar in shape to the core pieces 35, 36 with core pieces 51, 52 forming one core package on one side of the core 31 and the core pieces 53, 54 forming another core package on the opposite side of the core 31. The regulating windings 55 - 58 are connected in series with the main winding 34 to be regulated as is shown in Figure 8, although the two windings of each core package are wound in opposite directions.

The core pieces 51, 52 (or 53, 54) of each core package are movable together between outer positions (one of which is shown in Figure 7c) on opposite sides of a centred position (shown in Figure 7b). Suitably each core package is movable in an arcuate path between its outer positions. In the outer positions of the two core packages shown in Figure 7c, all the leakage flux passes through the core pieces 52 and 54. In the other outer positions of the core packages, all the leakage flux passes through the other core pieces 51 and 53. Since the windings 55 and 56 (or 57 and 58) are wound in opposite directions, by moving each core package towards one or the other of the outer positions from the centred position it is possible to add or subtract voltage so that regulation will be of a plus/minus kind. An advantage of the transformer 50 over the transformer 30 is that the leakage flux will always be collected by a core package in whatever position it occupies.

Figures 9, 10a and 10b illustrate another embodiment of a transformer 60 according to the invention. In transformer 60, the leakage flux at the ends of the winding assembly are collected by winding "halves" or coils 61 - 64, connected in series with the main winding 34 (see Figure 11), instead of core parts. The coils 61 - 64 are connected in series with the main winding 34 to be regulated. The coils 61 and 62 ar positioned at the upp r end of the winding assembly 33 and the coils 63 and 64 are positioned

at the low r end of th winding assembly 33, the coil 61 being connected directly to the coil 63 at one side of the core 31 and the coil 62 being connected directly to the coil 64 at the other side of the core. As can be seen in Figures 10a and 10b, the coils 61 and 62 are positioned partly between the upper end of the winding assembly 34 and the upper yoke of the core 31 and the coils 63 and 64 are positioned partly between the lower end of the winding assembly and the lower yoke of the core.

The positions of the coils 61 - 64 can be movably adjusted relative to the core limb 32 as indicated by the double headed arrows in Figures 9, 10a and 10b so as to adjust the amount of leakage flux passing through the coils. In this manner the winding 34 is regulated.

In each of the transformers 30, 60 and 60 the leakage flux is used in a positive manner to regulate the voltage of the transformer. Thus regulation is achieved without the use of a tap-changer.

The winding cable used for forming the winding assemblies and regulating windings preferably has conventional non-superconducting conductors for the inner conductor means. However it is possible for the inner conductor means to comprise superconducting means, e.g. elongate high temperature superconducting material wound around a support tube through which cryogenic fluid, such as liquid nitrogen, is passed.

The electrical insulation of a transformer according to the invention is intended to be able to handle very high voltages and the consequent electric and thermal loads which may arise at these voltages. By way of example, a transformer according to the invention may have a rated power of more than 1000 MVA and with a rated voltage of up to 400kV to 800 kV or higher. At high operating voltages, partial discharges, or PD, constitute a serious problem for known winding insulation systems. If cavities or pores are

present in the insulation, internal corona discharge may arise whereby the insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical winding insulation of a transformer according to the present invention is reduced by ensuring that the inner layer of the insulation is at substantially the same electric potential as the inner conducting means and the outer layer of the insulation is at a controlled, e.g. earth, potential. Thus the electric field in the intermediate layer of insulating material between the inner and outer layers is distributed substantially uniformly over the thickness of the intermediate layer. Furthermore, by having materials with similar thermal properties and with few defects in the layers of the insulating material, the possibility of PD is reduced at a given operating voltages. The transformer is thus able to withstand very high operating voltages, typically up to 800 kV or higher.

CLAIMS

1. A transformer (30) including a core (31) having a core limb (32), a first winding (34) to be regulated wound around the core limb (32) and having opposite ends, at least one regulating second winding (37,38) and moving means for moving the at least one second winding (37,38) relative to the first winding (34), whereby in use of the transformer there is a leakage flux at opposite ends of the first winding (34), characterised in that the transformer (30) further includes flux collecting means (35,36) which is separate from the core (31), which comprises said at least one second winding (37,38) and which is arranged to provide a leakage flux path from one to the other end of the first winding (34) and in that said at least one second winding (37,37) is connected in series with said first winding (34).

2. A transformer according to claim 1, characterised in that the flux collecting means comprises at least one core piece (35;36), separate from the said core (31), on which the at least one second winding (37,38) is wound, the or each core piece having opposite end portions (35a,35b; 36a,36b) arranged at opposite ends of the first winding (34) and a connecting portion (35c;36c) connecting the said end portions.

3. A transformer according to claim 2, characterised in that said at least one second winding (37,38) is wound on the connecting portion (35c,36c) of the at least one core piece (35,36).

4. A transformer according to claim 2 or 3, characterised in that two of said core pieces (35,36) are provided which are arranged on opposite sides of the first winding (34).

5. A transformer according to claim 2 or 3, characterised in that a core package of at least two of said

core pieces (51,52,53,54) is arranged on each side of the first winding.

6. A transformer according to claim 5, characterised in that the two second windings (55,56 and 57,58) of each core package (51,52 and 53,54) are wound in opposite directions on the two core pieces of the core package.

7. A transformer according to claim 6, characterised in that the core pieces (51,52; 53,54) of each core package are mounted for movement together relative to the first winding (34) between a first limit position in which the leakage flux is collected at least mainly by one of the two core pieces of the core package and a second limit position in which the leakage flux is collected at least mainly by the other one of the two core pieces of the core package.

8. A transformer according to claim 7, characterised in that each core package (51,52; 53,54) is movable, e.g. along an arcuate path, through an intermediate position on movement of the core package from one to the other of said limit positions, the leakage flux being collected substantially equally by both core pieces when the core package is in said intermediate position.

9. A transformer according to claim 1, characterised in that the flux collecting means comprises the said at least two second windings (61-64) arranged at opposite ends of the first winding, the or each second winding at one end of the first winding being connected to a different second winding at the other end of the first winding.

10. A transformer according to any one of the prec ding claims, characteris d in that the first winding and/or the or each second winding is wound from cable (40) comprising inner electrically conducting means (41) and,

surrounding the latter, out r solid electrically insulating means (42).

11. A transformer according to claim 10, characterised in that said solid electrically insulating means (42) comprises magnetically permeable plastics material (43-45) within which the electric field, created by current passing along the cable, is confined in use of the transformer.

12. A transformer according to claim 10 or 11, characterised in that the electrically insulating means (42) is of substantially unitary construction comprising an inner layer (43) of semiconducting material in electrical contact with said electrical conducting means (41), an outer layer (44) of semiconducting material at a controlled electrical potential along its length and an intermediate layer (45) of electrically insulating material between the said inner and outer layers.

13. A transformer according to claim 12, characterised in that the semiconducting outer layer (44) has a resistivity of from 1 to 10^5 ohm-cm.

14. A transformer according to claim 12, characterised in that the semiconducting outer layer (44) has a resistivity of from 10 to 500 ohm-cm, preferably from 50 to 100 ohm-cm.

15. A transformer according to any one of claims 12 to 14, characterised in that the resistance per axial unit length of the semiconducting outer layer (44) is from 5 to 50,000 ohm.m^{-1}.

16. A transformer according to any one of claims 12 to 14, characterised in that the resistance per axial unit of length of the semiconducting outer layer (44) is from 500 to 25,000 ohm.m^{-1}, preferably from 2,500 to 5,000 ohm.m^{-1}.

17. A transformer according to any one of claims 12 to 16, characterised in that the semiconducting outer layer (44) is contacted by conductor means (10) at said controlled electrical potential at spaced apart regions along its length, adjacent contact regions being sufficiently close together that the voltages of mid-points between adjacent contact regions are insufficient for corona discharges to occur within the electrically insulating means (42).

18. A transformer according to any one of claims 12 to 17, characterised in that said controlled electrical potential is at or close to ground potential.

19. A transformer according to any one of claims 12 to 18, characterised in that the said intermediate layer (45) is in close mechanical contact with each of said inner and outer layers (43 and 44).

20. A transformer according to any one of claims 12 to 18, characterised in that the said intermediate layer (45) is joined to each of said inner and outer layers (43 and 44).

21. A transformer according to claim 20, characterised in that the strength of the adhesion between the said intermediate layer (45) and the semiconducting outer layer (44) is of the same order of magnitude as the intrinsic strength of the material of the intermediate layer (45).

22. A transformer according to claim 20 or 21, characterised in that the said layers (43-45) are joined together by extrusion.

23. A transformer according to claim 22, characterised in that the inner and outer layers (43 and 44) of semiconducting material and the insulating intermediate layer (45) are applied together over the conducting means (41) through a multi layer extrusion die.

24. A transformer according to any one of claims 12 to 23, characterised in that said inner layer (43) comprises a first plastics material having first electrically conductive particles dispersed therein, said outer layer (44) comprises a second plastics material having second electrically conductive particles dispersed therein, and said intermediate layer (45) comprises a third plastics material.

25. A transformer according to claim 24, characterised in that each of said first, second and third plastics materials comprises an ethylene butyl acrylate copolymer rubber, an ethylene-propylene-diene monomer rubber (EPDM), an ethylene-propylene copolymer rubber (EPR), LDPE, HDPE, PP, XLPE, EPR or silicone rubber.

26. A transformer according to claim 24 or 25, characterised in that said first, second and third plastics materials have at least substantially the same coefficients of thermal expansion.

27. A transformer according to claim 24, 25 or 26, characterised in that said first, second and third plastics materials are the same material.

28. A transformer according to any one of the preceding claims, characterised in that cooling means, e.g. air or liquid cooling means, are provided for cooling the core and windings.

29. A transformer according to any one of the preceding claims, characterised in that the core comprises three core limbs (2-4) arranged in the same plane and that at least one regulating second winding is associated with a winding assembly including a first winding for each of the three core limbs.

30. A transformer according to any one of claims 10 to 27 or claim 28 or 29 when dependent on any one of claims

10 to 27, characterised in that the said electrically insulating means (42) is designed for high voltage, suitably in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher.

31. A transformer according to any one of claim 10 to 27 or claim 28, 29 or 30 when dependent on any one of claims 10 to 27, characterised in that the said electrically insulating means (42) is designed for a power range in excess of 0.5 MVA, preferably in excess of 30 MVA and up to 1000 MVA.

32. A method of regulating a transformer (30) having a core (31) with a core limb (32) on which a first winding (34) to be regulated is wound, comprising collecting leakage flux at one end of the first winding (34) and transferring it to the other end of the first winding with flux collecting means (35,36) separate from the core (31) and including at least one regulating second winding (37,38) connected in series with the first winding (34), whereby the leakage flux is used to regulate the first winding (34).

33. A method according to claim 32, characterised in that the regulation of the first winding (34) is controlled by adjusting the position of the flux collecting means (35,36) relative to the first winding (34).

FIG. 1

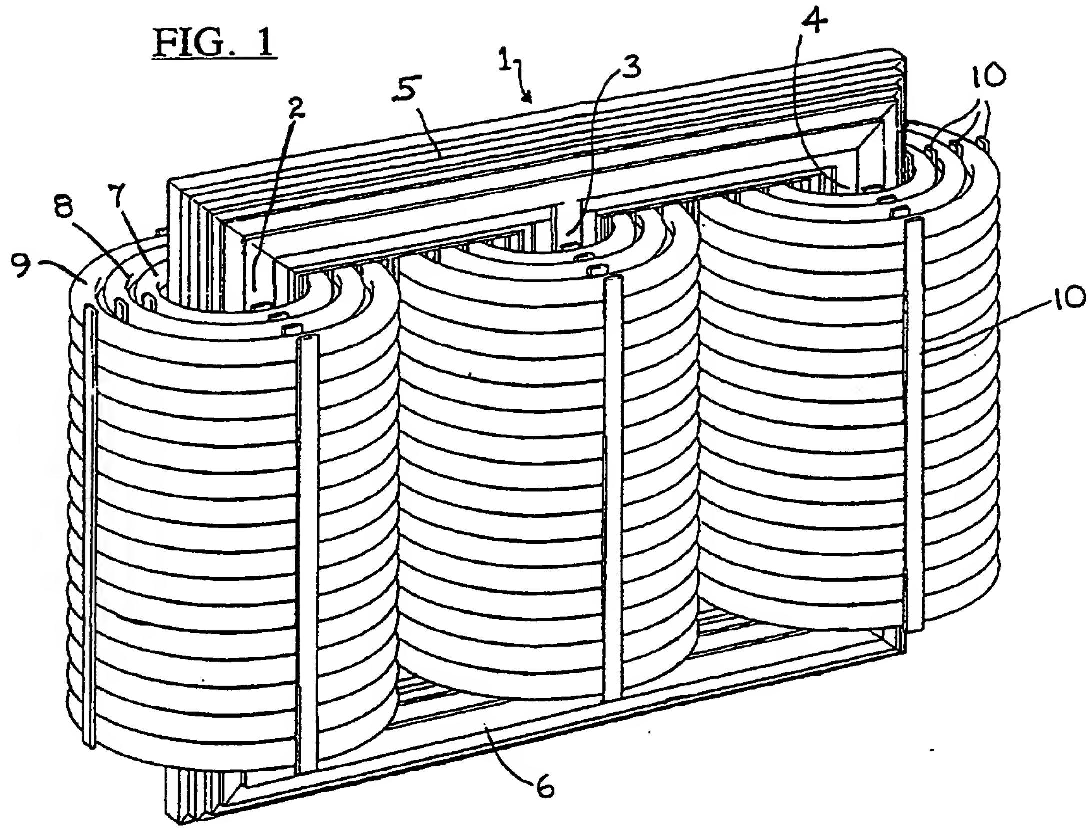
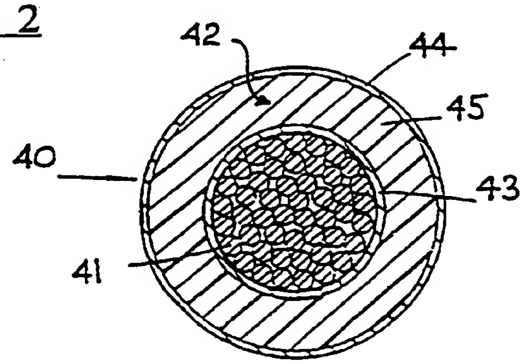


FIG. 2



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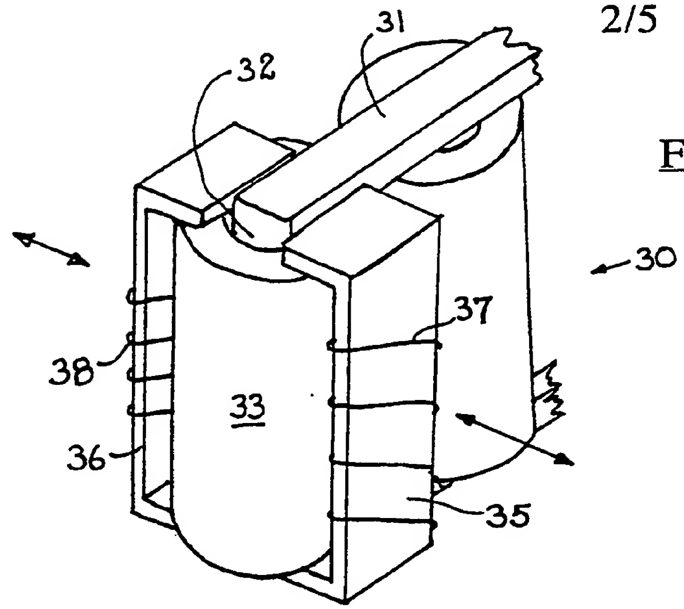
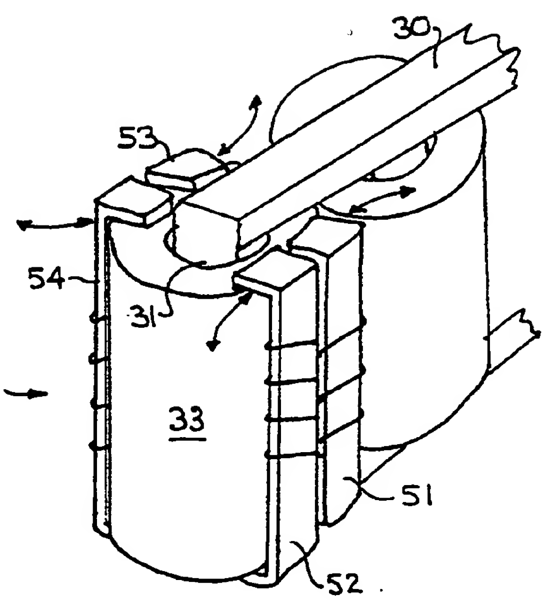


FIG. 3

FIG. 6



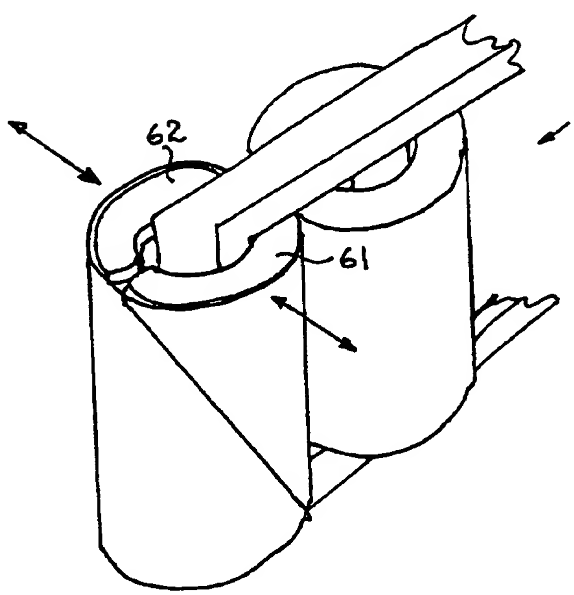


FIG. 9

FIG. 4a

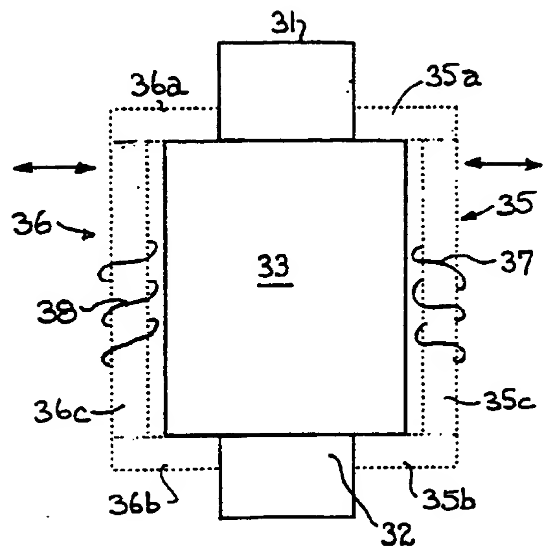


FIG. 5

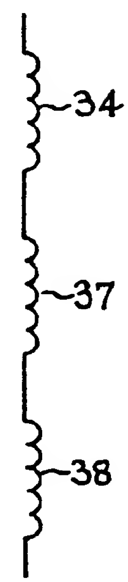


FIG. 4b

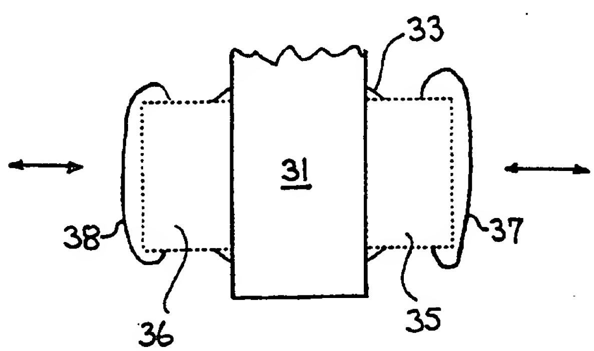


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FIG. 7a

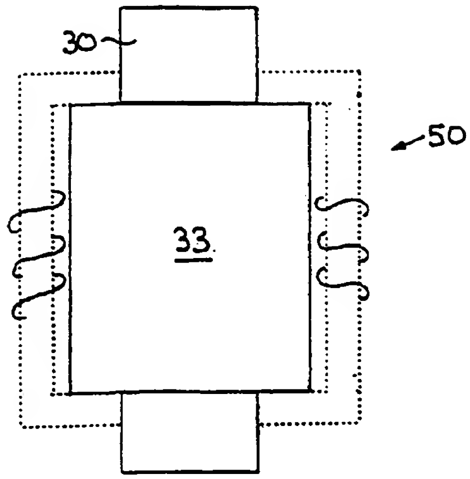

FIG. 8

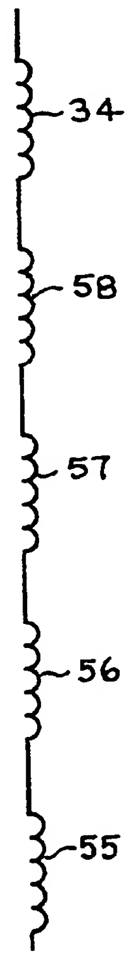

FIG. 7b

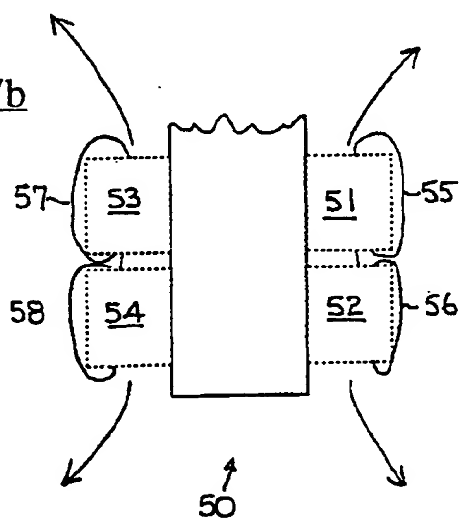

FIG. 7c

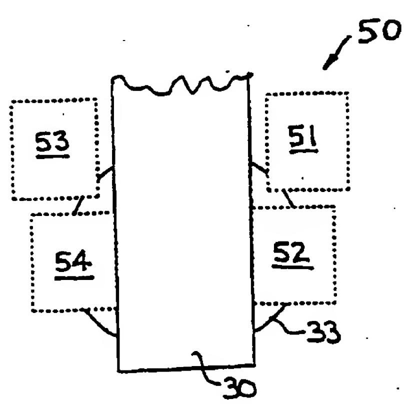

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FIG. 10a

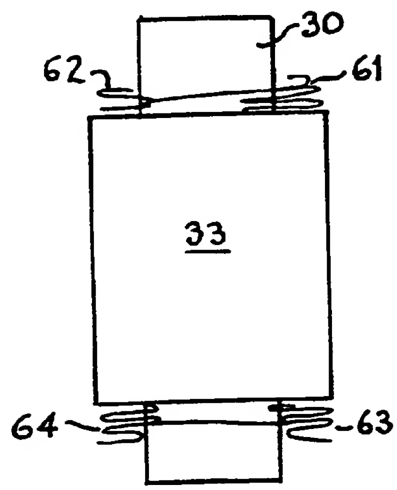


FIG. 10b

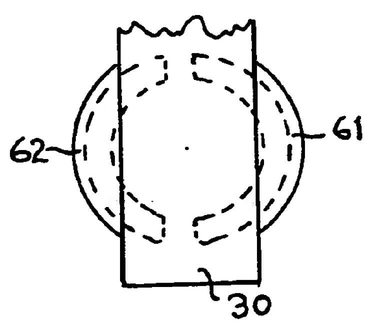
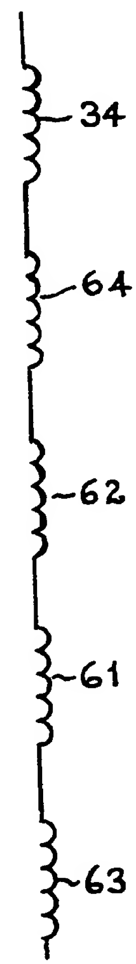


FIG. 11



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INTERNATIONAL SEARCH REPORT

Inte nal Application No
PCT/GB 98/02930

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01F29/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2 206 856 A (W.E.SHEARER) 2 July 1940 see figure 5	1-3,32, 33
A	FR 1 238 795 A (SIFE) 2 December 1960 see figures 1-3	4,5,29
A	FR 916 959 A (L.TESTUZ) 31 January 1947 see figure 2	8
A	DE 673 545 C (SIEMENS) 24 March 1939	
A	US 3 716 719 A (ANGELERY H ET AL) 13 February 1973	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 December 1998	30/12/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Vanhulle, R

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 98/02930

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 2206856	A	02-07-1940	NONE	
FR 1238795	A	02-12-1960	NONE	
FR 916959	A	31-01-1947	NONE	
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US 3716719	A	13-02-1973	NONE	